

# Measuring Consciousness

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## Abstract

A measurement based formula for consciousness,  $C$ , as a function of time  $t$ , is constructed. The formula depends on identifying a natural relevant self-generated, time-dependent dynamical process inherent in any entity. For human beings the relevant dynamical process identified is the ensemble of brain waves, observed in EEG measurements, that are represented in the model by their measured time dependent correlation functions. These correlation functions define the accessible dynamical state of the brain at any moment of time. From them a time dependent probability function,  $P(t)$ , is extracted by using a mathematical identity. According to information theory,  $-P(t) \ln P(t)$ , is a measure of the information contained in the brain waves. Consciousness,  $C$ , is defined by this information theory formula: it is not localized, does not depend on specific hardware details of the brain, but reflects the information content present in brain waves. Justifications, based on observational evidence, are given for the formula and it is shown that  $C$  reflects the degree of “awareness” that a person has at a given moment of time. The model explains the observed time delay between when a brain wave is seen to initiate an action and when there is awareness that the action has been initiated, in terms of the way brain waves processes information. Some testable consequences of the model, including the role dreaming sleep plays in long term memory storage, are discussed. It is also shown that non living entities have  $C = 0$ .

keywords: consciousness formula, correlation functions, brain waves, memory

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## Introduction

Consciousness, our personal higher form of “self-awareness”, is time dependent and has a limited focus of attention. For human beings it defines who we are. Using words and definitions to discuss consciousness is not helpful as words, without links to experience, form a closed circle and thus do not lead to understanding. But listing some of the properties of consciousness can be helpful. A first step is to distinguish between primary consciousness and higher consciousness. Primary consciousness is our awareness of the world and our knowledge of where our body ends and the external world begins. This form of consciousness is necessary for all living creatures in order for them to function. In contrast higher consciousness involves a thinking subject who is aware of his or her acts and also has awareness of mental constructions. For this higher form of consciousness to operate requires the subject to have memory. In trying to understand the nature of consciousness our approach is to relate it to something naturally linked to consciousness that is time dependent. Our choice is to pick some time dependent feature of the biological brain as neuroscience has convincingly linked consciousness to the brain Greenfield, 2001[1].

Many approaches for understanding the nature of consciousness using different features of the brain and with very different starting points have been proposed. An incomplete list of references where some of these wide variety of approaches are discussed are: non-linear mathematics [Scott, 1995] [2], quantum theory [Penrose et al, 1995, 2011][3], quantum field theory [Vitiello 2001, Vitiello and Freeman, 2006, Stanford Encyclopedia of Philosophy, 2011][5], [Jibu et al, 1996] [4], [Chakraverty, 2014][6], holography [Pibram, 2004][7], evolutionary biology [Edelman, 1992][8], neuroscience [Crick, 1994][9], philosophy [Chalmers, 1995][14][Dennett, 1996; Putnam, 1988] [12][11], computer science [Churchland, 1986; Lloyd, 2010] [10][15], cognitive science [Hobson, 2000] [23] linguistics, psychology [James, 1977; Blackmore, 2002][19] [13], psychiatry [Hebb, 1980; Baars, 1988] [18] [20], theoretical physics [Josephson, 1992] [16] and religion [Nikhilananda, 2005] [28]. Further references can be found in the works of the authors we have listed.

Recently Tononi [Tononi, 2008] [29] has made an interesting proposal to understand the nature of consciousness. In this work consciousness is related to the structure of the biological brain by an explicit formula. The mathematical formula is constructed using the idea of integrated information, which is a rule for determining the information present in the entire brain that is more than the information present in brain subunits chosen in a special way. Consciousness,  $C$ , is defined as the difference between the information content of the entire brain,  $E$ , and that contained in the sum of a certain prescribed set of brain subunits  $\sum S_i$  regarding them to be independent unconnected entities. Thus  $C$  measures the degree of entanglement present among brain subunits which makes  $E$  different from  $\sum S_i$ . The quantity of integrated information present in a system is taken to be a measure of its state of consciousness, while the quality of a conscious experience depends on a “shape” in the space of qualia. The process of discarding informations introduced by Tononi [Tononi, 2008][29] can be represented symbolically as the difference  $C \rightarrow E - \sum S_i$ . It would be zero if the information content of the subunits, regarded as independent entities, determined the information content of the entire brain.

The measure for  $C$  introduced in this way is broad enough to be extended to discuss the consciousness of all entities whether they are living or non-living as all that is involved is the notions of units, subunits, entanglement and probability. Hence consciousness is a universal property of the universe and levels of consciousness can be calculated. Evaluating the conscious-

ness value for a human being at a given moment is, however, not easy. It requires assigning probabilities and calculating the deviation of brain subunits from being independent entities from a knowledge of how they are linked. Nevertheless, conceptually the framework of Tononi *etal* represents a significant step forward as it introduces the idea of a complex system with subunits all which are massively linked as a model for understanding consciousness. It also puts forward for the first time an operationally defined formula for consciousness.

In this paper, influenced by the novel idea of Tononi [Tononi,2008] of a formula for consciousness, we propose a new and different formula for consciousness that can be calculated and is directly related to observation. Like the approach of Tononi [Tononi,2008] our measure uses ideas from information theory and is general enough so that it can be used to discuss the consciousness of atoms, of plants as well as of human beings. Questions about the nature of consciousness can, in our approach, be framed in terms of measurements. The basic idea is to view consciousness as a time-dependent process so that any attempt to capture its important features is expected to involve a natural time dependent process associated with the entity of interest be it a human being, or a plant or an atom.

How are we to select the “correct” natural relevant time-dependent process for an entity? There is no universal rule for making this choice. However the choice should be shown to capture essential features of the system of interest. For human beings we feel a good choice is to use brain waves [Hobson, 2000][23], observed in EEG, and their measured time dependent correlation functions. These correlation functions define for us the dynamic state of the brain. We will justify this choice by showing, shortly, how a brain wave picture can explain basic features of the brain and also state recent results from neuroscience that show that brain waves do reflect dynamic features of the brain.

We start with two recent results from neuroscience and then we discuss in greater detail , in a number of sections, how a brain wave picture can explain basic features of the working brain. The first result from neuroscience [Alexander, 2013][25] shows that brain waves respond to external inputs in an unique way thus suggesting that they are sensitive to the fact that we change with time and are never the same. We change due to changes in our environment and changes that are constantly taking place in our body.

The second result [Colgin et al, 2009][34] is very significant. It shows that incoming information, reflected in brain waves, is repeatedly compared by the the brain waves to information stored in memory by a switching mechanism that operates at the cellular level. The switching rate is several times a second. This result establishes a direct link between brain waves and memory. We interpret the result to mean that the comparison of incoming information with information stored in memory is necessary in order to place the new information within the context of previous events. The comparison allows us to categorize the nature of the incoming information and thus, become aware of it. The iterative comparison process takes time and introduces a delay of a fraction of a second between that point of time when a brain wave indicates an external event has occurred and when we, at a slightly later time become aware of it. Such delays between brain wave reactions to an event and awareness of the event are known to happen [Libet, 1985] [17].

Let us summarize the basic features of our approach. Our starting point is the conjecture that the observed dynamic brain waves [Hobson,2000] [23] that are synchronized electrical pulses between masses of neurons communicating with each other, capture the dynamic state of the brain. The dynamic state of the brain represents the totality of time dependent information

contained in the brain at any given moment. This includes emotions, facts, images, sounds, taste and memories. We should make it clear that we are not saying that the brain waves observed contain in them all this information but that they have access to all of the portion of brain information which is quickly available at any given instant of time. This set of “rapidly available information” is what we call the dynamical state of the brain. Thus brain waves potentially contain thought, can access memory, and also contain in them information about the state of all our organs. All of this information is potentially contained in the measured brain wave correlation functions. Thus the measured time dependent brain wave correlation functions reflect the dynamical state of the brain. From these correlation functions, we show in Appendix B, how an associated time dependent probability function  $P$  can be constructed. The consciousness measure  $C$ , for human beings is then defined by the information theory formula (Appendix A)[Shannon, 1948] [30] to be  $C = \sum -P \ln P$  where the sum is over the measured electric potentials present in brain waves at time  $t$ .

The measure of consciousness proposed is global and time dependent. It is based on integrating the brain wave spatial information and can take a continuum of values thus allowing different degrees of consciousness to be possible. We show how this function  $C$  captures our state of awareness. For a person in deep sleep, in coma or undergoing an epileptic fit our consciousness formula gives a low value. The quality and meaning of a conscious experience is given by the three dimensional dynamical shape of measured potentials at different points of the brain created by the dialog between the input information signal and memory [Colgin, 2009][34]. The time scale of this unfolding is expected to be a fraction of a second.

We show that all non-living entities described by deterministic classical laws of physics as well as atoms in their stationary state governed by quantum laws have zero consciousness (Appendix D). For living creatures, without a brain, such as trees, an appropriate dynamical process is the way communications for cell growth and repair take place. Correlation functions for such a process could be used.

Speculations on the consciousness of the Universe that follow from our formula are given in (Appendix C).

We next turn show how the brain wave picture can be used to answer the following set of questions:

1. What is the primary function of the brain?
2. What are the basic features of the brain?
3. How are memories formed?
4. Why do we dream and how do we think?
5. How do we converse?
6. What is the self?
7. What molds our consciousness?

## **What is the primary function of the brain?**

We conjecture that the primary function of the brain of a creature or person is to ensure the creature's or person's survival [Rose, 1992][35]. But the word "survival" needs to be clarified: it is not straightforward. At one level survival means survival of a person but we know that if this goal is in conflict with the survival of one's children or one's loved ones or one's community or one's nation or even one's abstract ideas of justice or truth or freedom then the personal survival goal can and often is set aside. Thus we immediately see that survival of the person is not an absolute law for the brain. The breaking of this rule suggests that perhaps the brain is guided by a more global view of what the concept of survival means. These broader set of reasons that allow the brain to put aside the imperative of personal survival seem to be based on a set of values that include emotions, friendships, family loyalties as well as loyalty to abstract ideas such as those of justice, freedom and truth. Defending these values by even sacrificing ones life, may perhaps, help the community to move closer to a goal that the whole human race seeks. Perhaps such a goal can be understood in terms of evolution. Thus provisionally we can say that the brain tries to ensure the survival of a person but that under certain extreme conditions this goal can be set aside in order to satisfying certain abstract notions.

We now continue our quick tour of ideas by highlighting a few features of the brain.

## **What are basic features of the brain?**

The brain of an adult weighs slightly more than one kilogram [Greefield, 2001; Popper and Eccles, 1977][1][40]. It has three parts, the cerebrum, the cerebellum and the brain stem. The brain is surrounded by a fluid, which, due to buoyancy, reduces the effective weight of the brain. The cerebral spinal fluid surrounding the brain, introduces a vibrational effect on the brain of a few Hertz. The brain of a human being consumes over 20% of the energy of the entire body although it is only has a few percent of the body weight.

In evolutionary terms the brain, this energy-guzzling brain organ clearly has successfully met all cost-benefit assessments required by evolution successfully and with "flying colours" !

The brain has two symmetric parts, which are massively interconnected. It has a stem like connection at the end which leads on to the spinal column and near this junction there is another smaller brain part called the cerebellum. It has been established that the cerebellum and spinal cord are responsible for monitoring and initiating quick reflex responses.

The brain is made out of special cells called neurons which are signal processing devices that receive signals through tree like structures called dendrites and send signals to other neurons either through private lines which are thin wire like structures called axons or use non-private means of communication by chemical means through the medium in which neurons are placed. The process of sending signals through axons is a amazing mix of electric impulses along axons and either chemical or electric processes which then operate at axon junctions called synapses. The chemical synapse junctions use special chemical neurotransmitters to carry information across the junction. There are also secondary messengers that are the neuron's internal messenger molecules which, by their action, can change the physiological properties of neurons and synapses either, for brief or long periods, of time. The strengthening synapses occurs for both short term and long term memory storage. However the mechanism for accomplishing this goal is different for the two cases. Long term memory requires protein synthesis initiated by com-

munication from synapses using second messengers to the neuron's nucleus while short term memory requires only transient cellular changes that do not involve protein synthesis, may require sleep memory consolidation [private communication, M.Ramaswami, Trinity College Dublin,2016] [42].

Besides neurons, axons and dendrites there are also a very large number (more than tenfold the number of neurons) of glial cells in the brain. These cells play a variety of roles. Microglia move around in the brain consuming dead cellular debris. Other glial cells form myelin, the insulating wrapping surrounding axons, while others are physically able to cover or uncover regions of communication between neurons thus modifying inter-neuron information flow. Thus glial cells play an important part in the brain's information processing system [O'Shea, 2002] [37].

There are over  $10^{11}$  neurons in the brain which have over  $10^{14}$  interconnections. Painstaking experiments have established that different parts of the brain control different activities. Thus there are centers for processing sight, touch, speech, hearing, taste, breathing, muscular movement and so on. The processing of sight uses the largest array of neurons. There are also special places where input information from the different senses meet. These are called the associated cortex. Some parts of the brain, called the neocortex, are associated with thinking [Kurzweil, 2012][38] while other parts transfer short-time memory to long term memory. It is an incredibly complex, open, dissipative, time-dependent system.

A basic dynamical feature of the brain is that it operates in three well defined states. These are the waking state, the dreaming state and the state of deep sleep [Hobson, 2000][23]. It is found that associated with these states there are specific, detectable, electrical brain waves ranging in frequency of less than 3 Hertz for deep sleep (Delta waves), which are widespread, 4 to 8 Hertz for the dreaming state (Theta waves) with a regional distribution that can involve many areas of the brain, 8 to 12 Hertz for the normal awake state (Alpha Waves), usually involve the entire lobe with a strong concentration in the occipital region when the eyes are closed, while frequencies above 13 Hertz to 40 Hertz represent a super alert state (Beta and Gamma Waves). These waves can be very localized. All the brain waves listed are always present but, depending on our state of wakefulness, specific forms of these waves might be dominant. For example, when a person opens his or her eyes the  $\alpha$  waves diminish and the  $\beta$  waves increase. Recent research work has also established that when a person starts an activity a unique brain wave pulse with directionality is generated. If the same activity is repeated the pulse created is different [Alexander, 2013] [25]. If brain waves do represent the state of the brain, this would make sense as the person has changed between the two sessions of activity. Recent research [Colgin et al,2009][34] , mentioned earlier, has also identified that in the hippocampus region, Gamma waves of lower frequency access memories of the past while those of higher frequency contain current information. Furthermore the brain cells switch between these frequencies several times a second and thus attend to one kind of information at a time [Colgin et al, 2009][34]. We interpret this result to mean that there is a constant comparison of incoming information with that in memory and that this process is essential for understanding the meaning of the incoming information.

There are no constantly present brain waves in the cerebellum. The ones which appear there are in response to inputs and are in the Theta-range, the Gamma-range or are in Very Fast Oscillation range (over 80 Hertz). Oscillatory behavior requires excitatory neurons. In the cerebellum there are a few such excitory neurons in the form of granule cells. Recent work

[Knopfel, 2008][22] has shown that the Gamma and, the Very Fast Oscillations are generated in the cerebellum when external agents are introduced but these oscillations do not come from the excitatory granule cells. They come from the inhibitory neurons that are present. In addition the observed frequencies seem to correspond to ones observed in the cortex under similar conditions of excitation.

The human brain receives information about the external world from its organs of sight, sound, taste and touch which are located at the body boundary and it also receives internal information about the body organs through the nerve cells that are distributed throughout the system. From these internal signals the brain is aware of the location and state of each of the organs of the body.

The external information signals received by the brain encode three-dimensional data (for sight and sound) as well as non-dimensional data (taste and touch) received by two dimensional sensing organs, our skin, the surface of our tongue and the surface of our retina. By processing this information the brain recreates a three-dimensional visual world which gives us awareness of our spatial boundaries and orientation. This reconstruction is vital for movement, and for survival. Consequently a large part of the brain is used to process visual information. For blind people the body orientation and boundary picture needed is done using the information received from the senses of touch and sound.

The process of reconstruction of the external world and the constant monitoring of the state of our internal organs necessary which are both essential for us to live successfully in the world. We conjecture that both of these brain activities are reflected in the brain waves observed. Brain waves change when, for instance, when we open our eyes or hear sounds or when we faint. We conjecture that brain waves also contain potential thoughts.

The brain is important only for creatures that move. This fact is demonstrated dramatically by the example of an extraordinary sea creature, the sea squirt, Greenfield, 2001][1] which starts life as a moving creature but at maturity settles down at one spot. When this happens the sea squirt digests its own brain!

An important feature of the brain is that its memory storage capacity is enormous, but the input information it receives ( $\approx 10^7$  bits per second for visual data,  $10^5$  bits per second for hearing and  $10^6$  bits per second from the skin), is many orders of magnitude greater than its estimated processing capability of  $\approx 50$  bits of information per second [Markowsky] [45]. There are several ways in which this information bottleneck is addressed by the brain. It tends to disregard uniform, repetitive inputs [Greenfield, 2001][1], it compresses the incoming information by a process of filtering and it focuses on specific tasks that it deems to be important disregarding other events in this process. The natural behavior of the brain is to note changes when they occur. When we witness an event different people might report the event differently. This observation can be understood to be a consequence of the information bottleneck as different persons can choose to focus on different aspects of the event thus blocking awareness of some features of what occurred. The focus of attention determines the set of input data the brain processes for awareness.

Let us now continue our whirlwind tour of ideas by examining memory.

## How are memories formed?

The defining characteristics of a human being are the ability to speak, to make tools, to think, dream and innovate. None of these could happen without memory. Memory defines who we are. Neuroscience has by years of patient and imaginative work established that the formation of memories leads to changes at the cellular level [Rose, 1992][35]. When a memory is formed in chickens [Rose, 1992][35] it was found that there are associated long-term, fast, electrical oscillations lasting for several hours and confined to two bursts of activity separated by a six hour gap. There was at the same time a dramatic increase in the number of information receiving stations within the brain, the dendrites. For the chicken these two long-term, fast, bursts of electrical oscillations [Rose, 1992][35] were identified with the process of long-term memory information storage in two widely separated regions of the brain. The memory classification markers used at the two locations were different, one was colour based and the other was shape based.

This result that cellular level changes were observed in the chicken, was consistent with earlier work that established a link between the activation of the sense of vision and specific cellular changes. In this work it was found that there was an increase in the number of axon junctions (synapses) as well as an increase in protein synthesis in the visual cortex region. This result linked cellular level changes to vision. For cellular changes to happen, DNA transcription is required that results in RNA directed synthesis of specific proteins necessary for changing the structure of the cell.

To paraphrase Rose [1992] [35]: The brain synthesizes proteins at a rate higher than that for any other tissue. This process can be stopped for several hours by injecting high doses of certain antibiotics. It is found that rats, treated in this way, could not memorize new tasks during the lifetime of the antibiotic inhibitor in the animal. However, no other aspect of the animals behavior seemed to be affected. Memory formation, for rats, seems to require cellular changes. It was also established that after a memory is formed in a chicken, removing the dendrites, required to form the memory, did not affect the ability of the chicken to recall the memory. The memory remained secure but it is not known where this new memory is stored!

Where long term memories are stored is a mystery but the process of memory storage is beginning to be understood. It is known that certain parts of the interior of the brain, the thalamus and hippocampus, are regions where the process of converting short term memory to long term memory resides. These are also regions of the associated cortex where different sensory inputs meet. It is also known that during long term memory formation synaptic activity activates the transcription of some neuronal genes [O'Shea, 2002] [37] leading to the synthesis of several proteins. Synapses can talk to genes [Sutton and Schuman,2006][36].

It is accepted that memory formation and storage are driven by the primary goal of the brain to facilitate survival, defined in broad terms [Endel Tulving, 1991] [21]. This result was observed in chickens who were trained to avoid food of a certain color and shape. Clearly identifying suitable food was a survival issue for the chicken. Thus, motor skills and dexterity would also be regarded by the brain as survival skills and hence placed in secure and quickly accessible memory locations. Thus the nature of input information and its relevance for survival, as interpreted by the brain, play an important role in the way memories are stored. Possible factors used by our brain to decide how to classify information received are likely to include the environment, our interests, the emotional content of the words used, the facial expression and



body movements of the human observed as a source of the information. Hence words from a parent, which have great emotional content, will be stored securely with multiple links to other data *i.e* the storage will include the specific words heard, as well as associated images, emotions and sensory data. This rich interlinking process of storage means that these memories will have multiple locations, each location is based on the brain's classification scheme.

It is also clear that our memories are constantly being updated and linked to our previous experiences. They are not static. During the process of assimilating new information into our memory there are often moments of enlightenment when we suddenly see a new connection or a new perspective of what we had seen or heard before. These moments of insight are often life-changing transformational events. They are the result of either reacting to or reflecting on new or even old information viewed through the prism of our memory that suddenly make us aware of links between different strands of thought leading to us to have new creative insights.

Finally we conjecture that memory retrieval is carried out by brain waves triggered by environmental changes, human interactions or when required for tasks that require information and involve concentration and mental dexterity. But the central message we wish to stress is that memory is stored in a spatially distributed manner at the cellular level, using the brain's classification scheme that is based on a generalized notion of survival in a way we do not understand. This information is accessible to the neurons generating the observed brain waves and that the DNA of cells plays an important role.

## **Why do we dream and how do we think?**

There is evidence that potential thoughts present in brain waves are constantly upgraded by interactions with the external world and that the specific upgrade of information from short term to long term memory happens during our dreams [M.Ramaswami, 2016] [24]. The associated cortex is expected to play an important role in this process as it is a place where information from all senses are available. It is known that information is stored in the brain in diverse locations. One possible reason for this is that a word can have different meanings and evoke different emotions depending on the context in which it appears. Thus, for example, the word "red" could be stored in multiple locations associated with different emotions, interests and images. It might be associated with an emotion-charged event, with the color of a flower, of blood, with a sports club, a political party and so on.

During the conversion from short-term to long-term memory the new "files" introduced trigger responses from the existing ones and this leads to dreams. Thus young children should have more dreams as they are processing many new experiences of value while older people, exposed to fewer novel and exciting experiences, should dream less. As dream brain waves contain movement and action instructions that should lead to responses from the motor system these are blocked as the brain knows that dreams are by-products of the process of long term memory storage and thus movement and actions present do not require motor responses. A paralysis of muscles during dreams is known to occur.

For young children the emotion of fear could easily be triggered during this process of long term memory storage, leading to nightmares. In this picture an incoming word is mapped to the same word or an image associated with the word that is already in the brain memory.

Deep sleep on the other hand, we think, is the time when essential repair and maintenance

work on the brain is carried out. During deep sleep all incoming signals to the brain are known to be blocked [M.Ramaswami, 2016][24] so that this essential repair work, required for our wellbeing, can be carried out without disturbance.

Finally if one concentrates intensely on a certain problem, this effort could lead the brain to classify the problem as one important for survival. The brain would then attempt to transfer the essence of the patterns associated with the problem to long term memory. In this process of filing similar patterns stored might be activated resulting in the recognition of connections between ideas in widely different areas which could lead to the solution of the problem.

Very recent work in neuroscience [Huth et al, 2016] [39] establishes that words have multiple locations in the brain. This observation fits in nicely with the the picture proposed. It also fits with the following insightful remarks on “thinking” by Einstein. [32] which we quote: “ What precisely is “thinking” When, at the reception of sense-impressions, memory pictures emerge, this is not yet thinking. And when such pictures form series, each member of which calls forth another, this too is not yet thinking. When however a certain picture turns up in many such series then-precisely through such returns -it becomes an ordering element for such series, in that it connects series which in themselves are transition from free association or “dreaming” to thinking is characterised by the more or less dominating role which concepts play in it. It is by no reproducible signs (words); but when this is the case thinking becomes by means of that fact communicable... all our thinking is of the nature of free play with concepts...”

## **How do we converse?**

The picture of brain waves containing thoughts proposed here and research of Donaldson [Donaldson, 1978][33] on childhood learning of speech taken together suggest how we take part in a conversation.

It is suggested by Donaldson that children first grasp the meaning of what is being said and then progress to speaking. This idea gets support from the fact that when we read, the brain recognises each word as a whole. The order of the letters is not so important as long as the first and last letters are correctly placed. This can be understood if the meaning of a word is grasped by the brain by its pattern of letters rather than the letters themselves[37].

We suggest that a similar process takes place in a conversation. There too we start responding, not to words we hear, but by the meanings conveyed that we quickly grasp from a variety of clues including non-verbal ones, such as facial expressions, body language, previous conversations, the environment of the conversation and the people involved. These associative patterns lead our brain waves to access what are relevant ideas and thoughts to help us respond. The words that we hear are thus placed in the context of an anticipated framework whenever possible. Given this framework we can speculate on the mechanics of a response. Each set of words we hear is mapped to the ones already stored in our memory with associated pictures and images. But each word has multiple locations [Huth, 2016][39] with different sets of links hence this first step of choosing a specific mapping location for a starting word in a conversation opens up a set of images and a relevant thought chain associated to what we have heard. The brain then accesses two of its speech centers, one for accessing words from memory, the Broca area, and the other, the Wernike area, for arranging them in a coherent way. After this we respond to what we have heard by a string of words and thoughts. The same set of incoming words could give different responses depending on the choice made by the brain for

the starting location of the response. In choosing this starting location the brain takes into account the source of the words and the environment in which the conversation is taking place [Edelman,1992] [8].

We conjecture that a process of this type accompanies all of our non-reflex actions. Initially there is the thought of carrying out an action, registered by a brain wave change, this is followed by accessing the memory in order to interpret what appropriate motor or speech response required, which is then implemented. Our claim is that it is only after the memory is consulted do we become aware of what we have decided to do. This series of steps means that there should always be time-delays between the initial thought of an action (including speaking) and the conscious feeling of having initiated the action. Such time delays have been observed by Libet [1985][17]. Libet used electrical stimulation for different time lengths on patients with brain probes inserted. He found that a half second stimulation was needed before a patient felt the stimulus. It was also observed that the awareness of the decision to flex ones wrist seems to come after the brain has already started organizing the motion. It appears that a conscious experience has a lag time of a full half second after the stimulation is started [Blackmore, 2002] [13].

Both these observational results fit in nicely with the brain wave picture we have described and our interpretation of the experimental measurement of the attention switching time scale by Colgin et al. [2009][34] referred to earlier. It is remarkable that there seems to be a direct correlation between happenings in brain waves and measured effects on human beings. This correspondence is more than qualitative as brain wave measurements allows us to estimate the time delay results of Libet. We recall that gap in time between the high frequency Gamma information intake component and the lower Gamma frequency memory accessing component when measured was found to be a fraction of a second by Colgin et al [2009][34]. The length of this time delay is compatible with Libet's observations.

## **What is the self and consciousness?**

In our approach consciousness (awareness), for human beings, is linked to and captured by brain waves while the "self" is identified as the influencer of brain waves [Greenfield, 2001; Blackmore, 2002, Chalmers, 1995; Eccles, 1994][1],[14][?]. The "self" is thus essential for our existence. The influence of the "self" on brain waves [34] is inferred from the fact that the thought of an action, as shown in brain waves, happens before there is awareness of initiating the action [17]. But the way the "self" does this is not known. The richness of human consciousness comes from the richness of information stored in memory that is accessible to brain waves.

There is a primitive form of awareness and consciousness possessed by all living creatures, which allows a creature to distinguish between its prey and food and to distinguish where its structure ends and the external world begins. This ability allows living creatures to protect themselves from others by a variety of means and represents a basic form of self awareness. Hence all living creatures are conscious [Edelman, 1992][8]. For all living creatures we conjecture that their "self" organises survival information and information that allows them to recognize the difference between them and others.

Is there an identifiable source of this consciousness or of the "self" in a human being? Is this consciousness an inevitable emergent feature of a complex organism?[Edelman, 1992; Chalmers, 1995;Greenfield, 2001][8][14][1] We do not know. We can, however, point out that

elusive concepts and ideas can sometimes be described by some of their measured properties even though a clear understanding of what they “really” are may not exist. Even in physics the idea of an electron or proton is established by their measured properties. Perhaps we are faced with a similar situation in our attempt to understand the self and consciousness. We have experienced consciousness and are in the early stages of measuring it. If measured aspect of consciousness and the actions of the “self” become well established then over time we might begin to feel that we understand what they are.

Let us start by identifying events, places and people who are responsible for making us who we are.

### **What molds our consciousness?**

We start life with the history of our ancestors encoded in our DNA. This contains all mutations due to environment changes that our ancestors have experienced and at the end of this descent we have our immediate ancestors, namely our parents and grandparents. This DNA history contains old data about the human species and its wanderings. [8, 9] Thus at birth we arrive with certain predetermined physical characteristics and tendencies. From then on the environment in which we grow starts playing a significant role. By the environment we mean childhood upbringing, schooling, interaction with friends, books, films, music, social media, family, sports and so on. There is also the well known effect of group and community behavior. Group behaviour seems to be generated by sound, non-verbal clues, the presence of some catalysts which results in members of the group reacting in an atypical fashion while community behavior is decided by the norms and values of the community in which we live. This behavior sometimes transcends one's own community and in special situations one either rejoices or mourns together as a nation or as a human being.

All of these observed effects have an effect on a person's memory, sense of belonging, value system and consciousness. This rich set of environmental effects listed does not pretend to be complete but it underlines the fact that defining who we are is complex. Sometimes in this rich tapestry the influence of one person or one event can determine the course of our life and sets the goals that we seek.

But there are other important influences in our life that come not from the environment or from interactions with others but from more abstract sources. For instance there are books and religion, which tell us what are the aims of life and how life should be lived; then, there are legends and histories of our country. These legends very often suggest certain codes of conduct, certain aspirations and certain ways of regarding those not belonging to our own country, clan or community. They are thus of great importance for our perception of who we are.

Let us now bring together the different strands that we have discussed.

### **Putting the pieces together**

We have suggested that brain waves capture the “dynamical state” of the brain which we defined earlier and that consciousness has different layers. At the lowest level, consciousness distinguishes between the boundaries of a living creature and its environment. The higher levels of consciousness lead to a more complicated notion of self awareness, necessary for a person

to have aspirations, to have love, compassion, self sacrifice and other human feelings including a feeling of self worth. We have suggested that this higher level of consciousness crucially depends on memory which, in turn, depends on many things including our environment. We have described how memory formation and retrieval are a complex process. Finally we have suggested that besides the reasonable channels of memory formation such as through reading, hearing, personal experiences, human contacts there could be further presently unknown sources coming from our genetic history. Such a suggestion although speculative is not impossible given the fact that memories form at the cellular level where DNA plays a key role and we do know that the synapses interact with genes in the process of long term memory formation [O'Shea, 2002] [37]. The stunning amount of information present in our DNA is yet to be understood and the unfolding of potentialities present in DNA, given a suitable environment, continues to surprise us.

Faced with this very complex picture, can we hope to find a measure for consciousness? In recent papers Tononi [Tononi,2008][29] has suggested a way for doing this which we discussed in the introduction. It involves, as we explained, using tools of probability and information theory and measures the degree of entanglement of a given system. The entanglement measure starts from the hypothesis that the brain or any other object can be described by well defined subunits each of which has a probability to be in a specific state. The combined system, with each subunit in a prescribed state, however, has a probability which is not simply the product of the subunit probabilities because the system is entangled. This difference of probabilities, suitably defined is a measure of consciousness. In this measure the fact that the brain is living, or that it is a dynamic dissipative system does not matter. All that matters is that it is composed of subunits which can, in principle, be said to be in certain states with certain probabilities. The approach of measurement proposed is attractive but deciding on how to choose subunits is not clear nor is it clear what exactly is a brain state.

We transfer the basic idea of Tononi to relate consciousness to the global information present in the brain but replace his idea that entanglement of different brain subunit states defined by qualia by one in which the dynamically accessible part of the brain state is represented by measured time dependent brain waves correlation functions, not by qualia. We have stated a few results from neuroscience, which support such a choice. Thus the pair correlation functions  $G = G(V(x_1, t)V(x_2, t))$  for points  $(x_1, x_2)$  of the brain, at time  $t$ , is used to represent the state of the dynamical brain at time  $t$ , where  $V^a(x_1, t), V^b(x_2, t)$  represent measured electric field values at two points for waves  $a, b$  which can represent any one of the observed brain waves, *i.e* the  $\alpha, \beta, \gamma, \delta$  or  $\theta$  waves. We will suppress labels,  $a, b$  present in  $V(x, t)$  from now on. Thus  $V(x, t)$  really represents a collection of observational values:  $V^a(x, t)$  with the label  $a$  takes five values corresponding to the set  $\alpha, \beta, \theta, \delta, \gamma$  of brain waves.

Using standard tools of mathematics we show, in Appendix C, that the description of the dynamic brain state by correlation functions can be used to calculate a time dependent probability  $P(t)$  for the state. and universal measure for consciousness  $C(t) = -\sum[P(t) \ln P(t) - P(0) \ln P(0)]$  defined (Appendix D) using a basic formula of information theory given in Appendix B. The sum in the definition of  $C$  is over all the values that the set  $V_i$  can take. The special feature of this procedure is that  $P$  is not a theoretical construct but is extracted from measurements made on the brain. Thus  $C$  directly represents brain wave information. The measure is chosen to have the property that  $C(0) = 0$ . This is a important requirement. The absence of time dependence in the brain waves signals death and, hence, the absence of consciousness. Thus in our approach consciousness of a human being cannot be constant. It must

change with time.

It is clear that the measured correlation function,  $G$ , contains information from all of the brain waves observed and that this information has the imprint of the environment, the presence of other people and all other sources of information available to the brain. Brain waves depend on both internal as well as external information. This fact is incorporated in our model through a “current”  $J(x, t)$  that interacts with the brain wave fields. The current  $J(x, t)$  is composed of two pieces:  $J_I(x, t)$ , the internal current which represents all the internal bodily processes that are monitored by and influence the brain and  $J_E(x, t)$ , the external current which represents all the external sources which influence the brain. The external current is non-zero only on the boundary of a human being *i.e* all the external senses such as the eyes, ear, nose and skin. Because of these external inputs the brain wave measurements are expected to be environment-sensitive. Thus measurements made in a crowd, in a desert, in a factory, during a musical performance, or on top of a freezing cold mountain, are expected to give different results. The introduction of the currents  $J(x, t)$  allows us to introduce boundary conditions which will make  $C = 0$  outside a narrow range of temperatures and favourable range of environmental factors.

A curious consequence of our picture is that it assigns a constant space-time independent value for the consciousness of the universe which has an echo in the consciousness of human beings. This result is established in Appendix D. In Appendix E we calculate the consciousness of an assembly of hydrogen atoms at room temperature, and for a single hydrogen atom and show that in both cases the consciousness value is zero. We also show that the consciousness of all non-living entities described by deterministic classical laws is zero.

## Concluding Remarks and Speculations

What then is the self and consciousness? We have suggested that the self initiates our thoughts and actions in a way we do not know and we have suggested a measure for consciousness and “self awareness”, for human beings using brain waves. A result from neuroscience [Colgin et al, 2009] [34] helps us to place awareness in the context of brain processes as it establishes that a constant dialog between informational signals and memory at the rate of a fraction of a second is seen in brain waves. We interpreted this dialog to mean that consultation with memory is required in order for a person to become aware of the nature of the incoming information he or she has received. In our brain wave picture it is suggested that the quality and meaning of a conscious experience is directly captured by the unfolding in time of awareness due to a context dependent dialog between the incoming information and memory. The unfolding time is expected to be a fraction of a second rather than milliseconds [Colgin,2009][34].

The approach proposed in this work leads to two immediate consequences. The first consequence is that brain waves reflect “awareness”, as we have just explained, hence a measure based on them capture an essential feature expected of a theory of consciousness. Furthermore, the measure proposed predicts that there should be a positive correlation between brain wave frequency and the level of consciousness. This follows from the formula proposed and the boundary condition that  $C = 0$  when brain waves have no time dependences. From this it follows that the consciousness value of a person in deep sleep, in a coma or with a brain injury is small, since in such a state the very slow  $\delta$  waves dominate leading to a small value for  $C$  while states with higher brain wave frequencies, representing higher levels of awareness, will have larger values for  $C$ . Thus the formula captures the degree of awareness of a person.

The second important consequence of our approach is that it explicitly notes that consciousness and life depend on the presence of both external and internal source currents that were introduced. These time-dependent currents drive the system and are solely responsible for the time dependences of brain waves. This observation means that consciousness is not determined simply by the hard-wiring of a person's brain but, rather on many features of the environment in which the person exists. Indeed, in the absence of the external sources we would not be alive as they represent both the supply of nutrition and information.

The choice we have made to relate a brain state to measured brain wave correlation functions can be justified on two grounds.

First of all individual cells in the brain die, new dendrites form so that the hardwiring of the brain is not static. Hence the self we imagine remains the same during all of these brain and body changes. It cannot be linked directly to the body but perhaps can be captured by the dance of electrons represented by brain waves. Thus brain waves are abstract patterns containing information which, although rooted in specific neuronal pathways, do not depend on whether specific neurons are alive or dead. These waves characterize who we are and provide the continuity of our identity that we seek. The entity that is unchanging during all bodily changes is identified by us as the "self". Evidence for the continuity of the self is provided by our memory.

The second reason for our choice comes from our speculation that brain waves contain potential thoughts, have access to our memory and monitor the brain and all other organs so that they do indeed provide a measure of our self and consciousness. To expand on this theme we point out that the monitoring carried out by the brain constantly compares signals generated in the body from those that are generated externally [Colgin et al, 2009] [34]. We know that this monitoring activity is very efficient and has the ability to distinguish the self from others even at the molecular level as shown by our immune system. In view of this brain waves are indeed an appropriate set of variables for describing features of consciousness and self awareness.

Finally the measure chosen for the consciousness of a human being has a natural interpretation as a rate of entropy production. A standard concept of physics. This concept firmly establishes the out-of-equilibrium nature [Landau and Lifshitz, 1978][46] of life and of consciousness because entropy only changes for systems that are not in equilibrium.

We suggest that perhaps disturbing thoughts and memories might be placed by the brain so that they are not readily accessible to us as a protective safety measure to help us survive and not be constantly distracted by these memories. The set of "locked" memories and thoughts might represent our subconscious.

A few remarks may be in order. First of all we have not tried to construct a fundamental model for either the brain or how memory formation occurs at the cellular level but have used direct measurements to construct what we call dynamic brain states and use them to construct associated probability functions that, combined with information theory, led us to a measure of consciousness,  $C$  which is time dependent.

Secondly observations suggest that there are very few constant brain waves in the cerebellum [Knopfel, 2008][22]. The ones that appear there do so in order to carry out specific motor related tasks so that this part of the brain contributes less to consciousness. However the model proposed suggests that  $\delta$  or low  $\Theta$  waves should be present in the cerebellum as these low

frequency waves we conjecture monitor our organs during deep sleep when essential maintenance work on the brain is carried out and should thus be present in all regions of the brain.

Thirdly we conjectured that during the dreaming state of sleep the motor regions of the brain should have a much reduced level of activity as the main centers of activity should be in regions of the brain that store long term-memory. It has been suggested in neuroscience that memory storage in quiescent form may involve sleep and dreaming [24].

Quantum mechanical or quantum field theoretical ideas appear in our approach only when we calculate the consciousness of quantum objects. There we found that non-living objects obeying either classical deterministic laws or quantum probabilistic laws have zero consciousness.

The speculations about the brain and consciousness that we have made have testable consequences. We list a few:

1. Consciousness is, in our model, a global dynamic property of the brain that depends on brain waves, the dance of electrons and ions, and is not tied down to the properties of specific cells or clusters of cells. It is time dependent. During deep sleep, for instance, it is small. The frequency of brain waves reflects the state of our consciousness.
2.  $C$ , the measure of consciousness proposed is the simplest. There is an hierarchy of measures that can be considered by using multiple time correlation functions. The consciousness measure will then depend on these multiple times. The multiple times should take into account the natural brain response times in the range  $\approx 1$  to  $\approx 200^{-1}$  seconds set by the oscillation frequencies of brain waves. The range given corresponds to that set by the slow delta waves and the very fast oscillation modes observed.
3. An insight of condensed matter theory is that knowledge of the structure of a complex system does not reveal its function.[5]. Consider a piece of matter. If we are given all the atoms and the way they interact in the system we would not know that, when disturbed, the system behaves as if it contains phonons, quanta that emerge once the material object is formed. Phonons are not present at the start. This observation means identifying brain structures with consciousness may not be possible.
4. When we engage in a conversation,  $\gamma$  brain waves and three areas, two for speech, namely the Broca and Wernicke areas and the regions of word memory storage should be seen to be active.
5. Brain wave correlation functions should reflect the working of our vital organs.
6. During dreaming sleep the active areas of the brain should be the locations identified with long-term memory storage. We expect that there should be a correlation between low long-term memory and lack of dreaming.
7. During deep sleep the active area should be diffuse and widespread as it is conjectured that in this phase repair and brain cleaning operations take place. We expect that there should be a correlation between poor mental abilities and lack of deep sleep.
8. The absence of constant brain waves in the cerebellum suggest that it plays a smaller role in consciousness.



9. The subconscious in the model corresponds to early childhood memories and memories of traumatic events which the brain seems to record in less accessible regions.
10. The fact that memory formation involves DNA suggests that the brain might be able to read and have access to “human history” memory.
11. Evolution has equipped the human species to respond to signals in rather narrow bands of frequencies of light and sound. It is also known that these bands change with age. It is possible that there are input signals which do affect the brain but which we do not detect directly. For example, we know that we are bombarded by bacteria and viruses through our skin, our eyes and nasal passages. They contain information which the brain can process.
12. The brain wave picture suggests that there could be a universal time-delay between when the thought of an action occurs and when the awareness of making an action happens. This result follows from our interpretation of the recent results of Colgin et al [2009][34] identifying a switching-time between the processing of current information and the accessing of memory within the brain that results in an awareness of a thought. This time delay is a fraction of a second. Such an interpretation can account for the observations of Libet [Libet, 1985][17], suggesting that decisions are made by brain thought waves before we become aware of making them.
13. The conclusion that the Universe has a space-time independent value of consciousness follows from the model. This “ Universal Consciousness,  $C_U$ , is all around us: we are immersed in it. All our time dependent consciousness is simply adding and subtracting a time dependent term from  $C_U$ . One can speculate on the relevance and importance of  $C_U$  for human beings.

We end by saying that although we have proposed a measure for consciousness we still do not know what it is or where it is located. We still do not know what seeing, hearing mean nor do we know what friendship, love, anger, loyalty , beauty are. These are all words that represent experiences and emotions. Perhaps the best we can do, as scientists, to understand consciousness is to try to capture its abstract essence by testable measurements. This remark also holds for matter. We do not know, for instance, what an electron “really” is. All that we can say is that it can be characterized by a set of properties that can be measured and that we can predict the way it behaves in different situations.

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## Appendix A: Basic Formula of Information Theory

Any device, system or process for generating messages is called an information source. Each source has an alphabet. A message containing information has regularities. It has statistical structure. A real source of information can be modeled, for example, as we do, by time dependent correlation functions, which contain a messages formed from the alphabet given by the measured values of the electric field  $V_i$  at large number of different points of the brain. These messages contain information that are of interest. If a time dependent probability function  $P(t)$  can be assigned to such a message then  $A = -\sum P_n \ln P_n$  is the average information per message. For  $P(V_1, \dots V_n)$  the sum is over all the  $V_i$  present in  $P$  i.e the range of values that they can take. The maximum value this sum  $A$  can take is called the capacity,  $K$  and is given by  $K = M \ln N$ , where  $M$  is the range of values the variables  $V_i$  can take and  $N$  the total number of source points possible. For the brain we can take  $N \approx 10^{14}$  then  $K \approx M \times 50$  bits. For visual perception the maximum rate of information processing is found to be in the range of 40 to 50 bits per second [Van Essen, 1991][43] while the information collected by the photoreceptive mosaic of the eye is  $\approx 10^6$  [44].

## Appendix B: Assigning Probability to Correlation Functions

Consider correlation functions of electrical fields  $G_{ij} = G(V_i, V_j)$  at any two brain points measured at times  $t_i, t_j$  for measured potentials  $V_i = V(x_i, t_i), V_j = V(x_j, t_j), j = 1, 2, \dots n$ . We suppose that measurements are made for a large number of point  $i_1, i_2, \dots i_n$ , and take the set of these measurements to represent a state of the dynamical brain at time  $t$  when  $t_1 = t_2, \dots t_n = t$ . We proceed to show how to assign a probability function  $P = P(V_1, \dots V_n)$  to the correlation functions. The case when the  $t_i$  values are different can also be considered. It lead to a multiple time probability function. We work out results for this case and then set all the  $t$  values equal. There is a well known procedure to assign a probability value to a set of correlation functions. We start from the set of measured  $G$  values and use the following identity, for the case where  $J = 0$ , namely

$$\begin{aligned} G_{ij} &= \frac{1}{Z} \int [dV_1 dV_2 \dots dV_n] e^{-\sum [V_m (G^{-1})_{mn} V_n]} V_i V_j \\ Z &= \int [dV_1 dV_2 \dots dV_n] e^{-\frac{1}{2} \sum [V_i (G^{-1})_{ij} V_j]} \end{aligned}$$

where  $\int [dV_1 \dots dV_n]$  represent integrations over the measured set of numbers  $V_1 \dots V_n$ . These numbers all lie in a given range of values defined for the each type of brain wave considered. To model the dynamic brain besides the measured electric fields  $V(x_1, t_1), V(x_2, t_2)$  we also need to introduce external and internal sources of information  $J = J_I + J_E$  which are space and time dependent and determine the values and time dependence of the functions  $V$ . This is done by the source terms  $\sum dz J_m V_m$  when this is done  $G \rightarrow G_J$  where,

$$(G_J)_{ij} = \frac{e^{-\sum [J_m (G^{-1})_{mn} J_n]}}{Z} G_{ij}$$

Let us consider the case of where only a single pair of measurements  $V_1 = V(x_1, t_1), V_2 = V(x_2, t_2)$  is used to describe the brain state. The probability  $P$  of this brain state, in the

model, is given by (setting  $t_1 = t_2 = t$ ,

$$P = \frac{1}{Z} e^{-\sum [V(x_i, t)(G^{-1})_{ij} V(x_j, t)]}$$

$$Z = \frac{(2\pi)}{\sqrt{|\det(G(V_i, V_j))|}}$$

Here  $\det|G|$  is a function of the measured correlation function  $G$  and  $i, j$  can take the two value, 1, 2. Then  $G_{11} = \langle V_1 V_1 \rangle$ ,  $G_{22} = \langle V_2 V_2 \rangle$ ,  $G_{12} = G_{21} = \langle V_1 V_2 \rangle$ , where  $\langle V_i V_j \rangle$  is the two point correlator at time  $t$ . For the case when  $N$  different point measurements are made for times  $t$ , we have the  $n$  point correlation function  $G(i_1, i_2, \dots, i_N)$  where  $i_1 = V(x_1, t)$ ,  $i_2 = V(x_2, t) \dots i_N = V(x_n, t)$  can be similarly expressed in terms of measurements. The corresponding probability function is

$$P = \frac{1}{Z} e^{-\sum [V_m (G^{-1})_{mn} V_n]}$$

$$Z = \frac{\sqrt{(2\pi)^N}}{\sqrt{|\det(G_{mn})|}}$$

In these expressions we can represent  $V_i$  by a dimensionless numbers by choosing a basic unit for measuring  $V_i$  say  $V_0$  which is time independent. Then  $V_i(t)$  is represented by the number  $V_i(t) \rightarrow \frac{V_i(t)}{V_0}$  and  $G_{ij} \rightarrow \frac{G_{ij}}{V_0^2}$ , a numerical dimensionless function. Generalising to the case when multiple time correlation functions are considered the procedure described can then be used to define a multiple time brain state. This description is much more detailed and is expected to contain information regarding the way the brain monitors our organs.

We should point out that we do not know the details of the source term  $J$  introduced. The term  $J$  is the sum of two different sources, as stated, namely the internal source  $J_I(x, t)$  which represents all the information that reaches the brain from the internal organs and the external source  $J_E$  which represents all information that reaches the brain from our sense organs as well as all the nourishment that the body receives. Thus a cooling breeze, a touch, the sound of music, reading a book, or taking part in a conversation will all be part of the external source.

The special feature of the approach described is that the postulated brain state is constructed from measurements of brain waves and their associated time dependent probabilities are obtained from them by using standard mathematical tools. In order for our analysis to apply the matrices  $G$  must have non zero positive determinant.

## Appendix C: Consciousness value of the Universe

The measure of consciousness  $C$  of a human being we introduce is,

$$C = -\sum [P \ln P - (P \ln P)_{t=0}]$$

It is a global time dependent number with no spatial dependence as all spatial dependences, originally present in  $V_i$ , disappear after the process of summing over the allowed values of  $V_1, V_2, \dots, V_n$  at different locations is performed. Setting  $C = 0$  when brain waves are time independent is a biological requirement as it signals death and hence the absence of consciousness. We satisfy this requirement by subtracting any time independent part that is present in  $C$ .

Thus our formula satisfies a basic biological constraint for human consciousness. We can expand on the importance of this condition further. In our construction of  $P(t)$  from measured correlation functions we introduced a source term  $J(x, t)$  which had two parts. One representing all sources of external information and nourishment and the other the internal source of time dependence represented by blood circulation and other internal organs functioning as dynamic units. It is clear that in the absence of these terms  $C \rightarrow 0$  as in the absence of these terms the requirements of life would be absent. Thus in order to be alive and have non zero consciousness  $P(t)$  must be time dependent and this time dependence comes from  $J(x, t)$ . It is a necessary condition.

We can consider the value of consciousness, not just for human beings, but for the entire universe. Our brain is an open dissipative system which takes in nourishment and information from the environment in a complicated way. If we take the universe to include all living and non living entities to be a closed system then the net global information/energy of the universe should have no time dependence. We can capture this feature by changing the sign of the time dependent part of  $C$  written and by assigning the universe consciousness this value. Then the consciousness for the entire Universe is

$$C_U = \sum (P_T \ln P_T)_{t=0}$$

which is time independent. This expression includes contribution from all human beings and all other constant sources of consciousness that exists. This is reflected by the subscript T in  $P_T$  and by the unspecified sum. We note that  $C_U$  represents a storehouse of information. From the point of view of the universe life is a local fluctuation represented by adding and subtracting time dependent parts. This is an unexpected result of our approach.

## Appendix D: Consciousness of Matter

Consider a collection of hydrogen atoms at temperature  $T$ . The states of hydrogen atom are well known from quantum theory. Hydrogen atom states can be described by a discrete set of oscillating frequencies  $\omega_n$  and corresponding probability wave functions. They are  $\omega_n = \frac{\omega_0}{n^2}$  where  $n$  can take only discrete values  $n = 1, 2, 3, \dots$  infinity [31]. The probability  $P_n$  of hydrogen atoms at temperature  $T$  to be in the state with frequency  $\omega_n$  is, from statistical mechanics [Landau and Lifshitz, 1978] [46], given by

$$\begin{aligned} P_n &= (2n + 1) \frac{e^{-\alpha \frac{\omega_0}{n^2}}}{Z} \\ Z &= \sum (2n + 1) e^{-\alpha \frac{\omega_0}{n^2}} \end{aligned}$$

where  $\omega_0$  is known positive constants and  $\alpha = \frac{\hbar}{kT}$ ,  $k$  is the Boltzmann constant. The sum is over all discrete values of  $n$ . Our formula for consciousness  $C$  is

$$C = \sum -P_n \ln P_n$$

But  $P_n = 0$  for hydrogen as  $Z = \text{infinity}$ . Thus  $C = 0$ . However this calculation is flawed as all the discrete set of values used do not exist at temperature  $T$ . The only ones that exist are those for which  $\frac{\omega_0}{n^2} < \frac{kT}{\hbar}$ . This requirement gives, at room temperature, only one allowed value for  $n$  namely  $n = 1$ . then  $P_1 = 1$  and again  $C = 0$  as  $\ln P_n$  is now zero. At higher temperatures more non zero  $n$  are allowed then  $C$  will be a time independent temperature dependent constant.

For classical planetary orbits each orbit has probability  $P = 1$  and hence the system has  $C = 0$ . This result will be true for all deterministic systems of classical physics as  $P = 1$  for any deterministic system.

For a single hydrogen atom with discrete frequency  $\omega_n$  the associated space averaged probability  $P_n = 1$  for each value of  $n$ . This result follows from quantum mechanics as the discrete frequency states of hydrogen atom are all stationary state *i.e* the probabilities of these states are time independent. Let us explain. The wavefunction  $\psi(x, t)_n$  for hydrogen in a stationary state of energy  $E(n)$  has the form  $\psi(x, t)_n = e^{-i\frac{E(n)t}{\hbar}} u_n(x)$  [Dirac, 1930] [31]. The space averaged probability is  $P(t) = \int d^3x \psi_n(x, t)^* \psi_n(x, t) = 1$ , Since  $\int d^3x u_n(x)^* u_n(x) = 1$ . Here  $\psi^*$  means taking the complex conjugate of  $\psi$ . Thus each discrete state has  $C = 0$ .